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Advancing Rural Welfare - The Role of Irrigation Technology in Ethiopia's Agricultural Sector

Alemayehu Geda[a]

Abstract

In Ethiopia, where agriculture forms the backbone of the economy and sustains the livelihoods of millions, the effective utilization of irrigation technology holds immense potential for transforming the agricultural landscape. However, despite the recognition of its importance, there remains a dearth of comprehensive research assessing the nuanced impacts of irrigation technology adoption on farm productivity and household welfare. By employing logistic regression analysis, this study delves into the determinants of household participation in irrigation technology, shedding light on the socio-economic factors that influence adoption decisions. The findings reveal that variables such as educational attainment, land under cultivation, social standing, livestock ownership, access to oxen, and distance to irrigation facilities play pivotal roles in shaping household choices regarding irrigation adoption. These insights not only contribute to a deeper understanding of the drivers of technology adoption but also provide valuable guidance for policymakers and development practitioners seeking to design targeted interventions aimed at promoting irrigation uptake among rural communities. Furthermore, the study employs rigorous matching techniques to assess the impact of irrigation participation on key welfare indicators, including calorie intake and farm income. Through meticulous analysis and robust statistical methods, the research establishes a clear and compelling link between irrigation adoption and improved household well-being, underscoring the transformative potential of irrigation technology in enhancing food security and economic resilience at the grassroots level. Moreover, by evaluating the effectiveness of different matching algorithms and ensuring covariate balance, the study enhances the reliability and validity of its findings, offering valuable insights that can inform evidence-based policy formulation and program implementation. These findings not only validate the importance of irrigation technology as a catalyst for agricultural development but also underscore the need for targeted support mechanisms and capacity-building initiatives to facilitate widespread adoption and maximize the socio-economic benefits for rural communities across Ethiopia. This study represents a significant contribution to the existing literature on agricultural development and technology adoption in Ethiopia. By elucidating the determinants of irrigation participation and providing robust evidence of its positive impacts on household welfare and farm productivity, the research serves as a valuable resource for policymakers, practitioners, and stakeholders working towards sustainable agricultural growth and rural development in Ethiopia and beyond.

Keywords: Irrigation Technology, Adoption Determinants, Household Welfare
JEL Codes: Q12, O13, O33

1. INTRODUCTION

Irrigation plays a crucial role in bolstering the national economy through various channels. One of its primary contributions lies in poverty reduction and the enhancement of livelihoods, particularly among rural communities. At the micro level, irrigation systems have been shown to substantially increase crop yields per hectare, leading to subsequent improvements in income levels, consumption patterns, and overall food security (Ahmad and Ali, 2016; Darko, et al 2016). The benefits of irrigation extend to impoverished populations, offering them opportunities for socioeconomic advancement. By enabling higher agricultural production and yields, irrigation mitigates the risks associated with crop failure, thereby providing a reliable source of income for rural households. Additionally, irrigation systems support year-round farming activities, creating avenues for both farm and non-farm employment opportunities, which are vital for sustaining livelihoods in rural areas. Research conducted by Hussain and Hanjira (2004) underscores the multifaceted advantages of irrigation for poverty alleviation and rural development. Their findings highlight how access to irrigation can significantly enhance the economic prospects of marginalized communities, empowering them to achieve greater financial stability and resilience in the face of agricultural uncertainties. Irrigation serves as a catalyst for smallholder farmers to expand their agricultural horizons and transition from subsistence farming to more lucrative market-oriented ventures. Research conducted by Bahn et al. (2008) underscores the transformative impact of irrigation in enabling smallholders to diversify their cropping patterns and embrace higher-value agricultural production for the market.

[a] Department of Agricultural Economics, College of Agriculture and Environmental Science, Haramaya University, Ethiopia

By providing reliable access to water, irrigation empowers farmers to cultivate a wider range of crops throughout the year, regardless of seasonal variations or rainfall patterns. This flexibility allows smallholders to explore new crops that are better suited to market demands and fetch higher prices, thereby enhancing their income potential and economic resilience. Furthermore, irrigation facilitates the cultivation of high-value cash crops that have greater market demand and profitability compared to traditional subsistence crops. Smallholders can capitalize on these market opportunities to improve their financial prospects and elevate their standard of living. Research conducted by Adank et al. (2008), Bahn et al. (2008), and Tolossa and Tafesse (2008) underscores the significant livelihood benefits associated with improved access to water for both domestic and productive purposes. Access to reliable water sources not only enhances income generation but also contributes to enhanced food security among communities. By ensuring reliable access to water for irrigation and other productive uses, communities can significantly increase their agricultural productivity and income levels (Namara, et al 2010). Farmers can cultivate crops throughout the year, irrespective of seasonal variations in rainfall, leading to higher yields and greater profitability. This increased income from agriculture serves as a vital source of livelihood for rural households, helping them meet their basic needs and improve their overall standard of living. Moreover, improved access to water for domestic purposes, such as drinking, cooking, and sanitation, has profound implications for household well-being and food security. Access to clean and safe water reduces the risk of waterborne diseases and ensures proper hygiene and sanitation practices, thereby improving overall health outcomes (World Health Organization, 2019). Additionally, reliable access to water for domestic use reduces the time and effort required for water collection, particularly for women and girls, allowing them to allocate more time to productive activities or education.

Ethiopia's high levels of chronic poverty, vulnerability, and food insecurity underscore the urgent need for strategic investments in water resources management. With agriculture serving as the cornerstone of Ethiopia's growth strategy, access to water is critical for unlocking the sector's potential and improving livelihoods for millions of Ethiopians. Research by Slaymaker et al. (2007) highlights the central role of water in Ethiopia's agricultural growth strategy. Despite the country's vast agricultural potential, growth in this sector is severely hampered by various constraints, including limited access to critical resources such as land and water. Addressing these constraints through targeted investments in water infrastructure and management is essential for enhancing agricultural productivity, increasing food security, and reducing poverty. Ethiopia's national policy priorities recognize the importance of water management in addressing these challenges. By prioritizing investments in water resources development and irrigation infrastructure, the government aims to mitigate the impacts of chronic poverty and vulnerability, particularly in rural areas where agriculture is the primary source of livelihood (Namara, et al., 2010; Karhan, 2017). Improved access to water for irrigation and other agricultural activities not only increases productivity and yields but also enhances resilience to climate variability and shocks. With a more reliable water supply, farmers can diversify their crops, adopt climate-smart agricultural practices, and mitigate the risks associated with erratic rainfall patterns. Furthermore, investments in water infrastructure have broader socio-economic benefits beyond agriculture. Access to clean water for drinking and sanitation improves health outcomes, reduces the prevalence of waterborne diseases, and enhances overall well-being, particularly among vulnerable populations (World Health Organization, 2008).

The agricultural sector in Ethiopia, despite its dominant role in the economy, has faced significant challenges, leading to a persistent problem of food insecurity. The sector's performance has been disappointing, with food production failing to keep pace with population growth (Molden, et al., 2007). This imbalance has been exacerbated by the degradation of natural resources essential for agriculture, further hampering productivity in the sector. Rapid population growth in Ethiopia has intensified the pressure on food production systems, exacerbating the challenges of food security. With the population expected to continue growing rapidly, the demand for food is projected to increase substantially in the coming years. Estimates suggest that Ethiopia will need to double its cereal production by 2025 to adequately meet the food needs of its expanding population. The implications of this growing demand for food are profound, as the agricultural sector struggles to cope with the increasing pressure. The inability to boost food production at a rate commensurate with population growth poses significant risks to food security, livelihoods, and overall socio-economic stability in the country (Renzaho, et al 2017). Addressing the challenges facing the agricultural sector in Ethiopia requires holistic strategies that focus on enhancing productivity, promoting sustainable land and water management practices, and investing in rural infrastructure and market access. Additionally, efforts to improve agricultural extension services, access to credit, and technology adoption are crucial for empowering smallholder farmers and enhancing their resilience to shocks and stresses (Chuku and Okoye2009). Moreover, tackling the underlying drivers of population growth through comprehensive reproductive health and family planning programs can help alleviate some of the pressure on food production systems. By promoting voluntary family planning and empowering women, Ethiopia can achieve more sustainable population growth trajectories that align with its agricultural and food security objectives.

Climate change presents a significant challenge to global food security, amplifying existing threats and vulnerabilities across all dimensions of the food system (Ingram, 2011). Its impact extends beyond agricultural productivity, affecting the availability, accessibility, utilization, and stability of food systems worldwide. Both food-exporting and food-importing countries, as well as those relying on subsistence agriculture, are vulnerable to the effects of climate change on food security. One of the primary ways in which climate change affects food security is through its impact on agricultural productivity. Changes in temperature, precipitation patterns, and extreme weather events can disrupt growing seasons,

reduce crop yields, and lead to crop failures. This directly affects the availability of food, particularly in regions where agriculture is the primary source of livelihood and sustenance.

Climate change can also affect the accessibility of food by disrupting transportation networks, increasing food prices, and reducing purchasing power, particularly among vulnerable populations (Al, et al., 2008). Changes in weather patterns may lead to more frequent and severe natural disasters, such as floods, droughts, and storms, which can damage infrastructure and disrupt supply chains, making it difficult for food to reach markets and consumers. Additionally, climate change can impact the utilization of food by altering nutritional content, reducing water availability for irrigation, and increasing the prevalence of pests and diseases (Myers, et al., 2017). These factors can compromise the quality and safety of food, leading to malnutrition, foodborne illnesses, and other health-related issues. Furthermore, climate change poses risks to the stability of food systems by increasing the likelihood of food price volatility, market disruptions, and conflicts over scarce resources. These disruptions can have far-reaching socio-economic implications, exacerbating poverty, inequality, and social unrest (Akech, 2020). Addressing the complex interplay between climate change and food security requires concerted efforts at local, national, and global levels. Mitigation measures, such as reducing greenhouse gas emissions and promoting sustainable land and water management practices, are essential for minimizing the long-term impacts of climate change on agricultural productivity and food systems. Adaptation strategies, including investing in climate-resilient agriculture, enhancing early warning systems, and improving social safety nets, are also critical for building the resilience of communities and food systems to climate-related shocks and stresses.

International cooperation, knowledge sharing, and financial support are necessary to support vulnerable countries and communities in adapting to the challenges of climate change and ensuring food security for all. By addressing climate change in tandem with efforts to improve agricultural productivity, promote sustainable development, and reduce poverty, the global community can work towards a more resilient and food-secure future. The main determinants of poverty in Ethiopia are closely linked to the heavy reliance on subsistence farming (Eyasu, 2020). Factors such as unpredictable rainfall, limited opportunities for off-farm employment, and a lack of alternative income-generating activities contribute to the vulnerability of those dependent on agriculture. Ethiopia's agricultural sector is predominantly rain-fed, making it particularly susceptible to the effects of variable rainfall patterns and recurrent droughts. These challenges not only impact agricultural productivity but also have broader implications for the country's economy. To address these challenges and promote sustainable growth and development, there is a recognized need to increase both public and private investment in irrigation development (Darghouth, 2005). By expanding access to irrigation, Ethiopia can reduce its reliance on rainfall and mitigate the adverse effects of climatic variability on agriculture. This strategic investment is seen as essential for decoupling economic performance from the vagaries of weather patterns and fostering long-term resilience. Government policies and initiatives aimed at promoting irrigation development are crucial for transforming Ethiopia's agricultural sector and improving livelihoods in rural communities. By providing farmers with access to reliable water sources for irrigation, it becomes possible to enhance agricultural productivity, increase crop yields, and diversify cropping patterns. Additionally, irrigation can create opportunities for off-farm employment and stimulate economic growth in rural areas. Furthermore, investments in irrigation infrastructure contribute to the overall resilience of Ethiopia's economy by reducing vulnerability to climate-related shocks and ensuring food security for vulnerable populations (Caliendoa and Kopeimig 2005; Degefa and Tesfaye 2008; Rosembaum and Rubin 1985; Fitsum, et al 2008). By supporting smallholder farmers and empowering rural communities, irrigation development can play a significant role in poverty reduction efforts and sustainable development initiatives across the country.

2. METHODOLOGY

The livelihoods in the zone are primarily based on mixed farming practices, which involve both crop production and livestock rearing. Crop cultivation and chat production serve as the main sources of income for the local communities. The area is known for growing a variety of crops, including sorghum, maize, common beans, highland pulses such as beans and peas, as well as various vegetable crops like potatoes, onions, garlic, and leafy vegetables. Additionally, fruits like bananas and mangoes are also cultivated in the district, contributing to the diversity of agricultural activities and potential sources of income for residents. This mixed farming approach allows households to diversify their agricultural activities, mitigate risks associated with crop failures or market fluctuations, and sustain their livelihoods through multiple income streams. The study utilized both primary and secondary data sources. Primary data collection involved the use of semi-structured questionnaires administered by trained enumerators. These questionnaires likely aimed to gather specific information directly from the participants, such as their farming practices, experiences with irrigation, and perceptions of its impact on their livelihoods. In addition to primary data, secondary data were gathered from various sources, including published and unpublished documents from agricultural and rural development offices, water resource development offices, and other relevant institutions. These secondary sources likely provided background information, context, and additional insights into the agricultural and water resource management practices in the district. Integrating both primary and secondary data sources allows for a comprehensive analysis and understanding of the research topic.

3. RESULTS AND DISCUSSION

The logistic regression analysis results presented in Table 1 provide insights into the factors influencing participation in the study. Each variable's coefficient, odds ratio, standard deviation (SD), and Z-value are reported, along with their respective statistical significance levels. The intercept term (Cons) has a coefficient of -1.4852, indicating the log odds of participation when all other predictor variables are zero. The corresponding odds ratio is 1.5177, suggesting that for every unit increase in the predictor variables, the odds of participation increase by a factor of approximately 1.5177. The Z-value associated with the intercept is -0.98. Among the predictor variables, several exhibit statistically significant effects on participation. For instance, Education has a coefficient of 0.2595 and an odds ratio of 1.30, indicating that individuals with higher education levels are 1.30 times more likely to participate compared to those with lower education levels. The Z-value for Education is 3.54, indicating a statistically significant effect at conventional levels (***). Similarly, variables like Social status, Livestock holding, Oxen owned, Cultivated area, and Irrigation distance also show statistically significant effects on participation, as evidenced by their Z-values (***) and significant odds ratios. On the other hand, variables like Experience, Family size, Soil fertility status, Market distance, Credit, and Extension do not exhibit statistically significant effects on participation, as their Z-values are not significant. The LR chi-square statistic tests the overall significance of the logistic regression model, with a value of 106.80 and a p-value of 0.0000, indicating that the model as a whole is statistically significant. The pseudo R-squared value of 0.3052 suggests that approximately 30.52% of the variability in participation can be explained by the predictor variables included in the model. The log-likelihood value is -85.223, providing a measure of how well the model fits the data. Finally, the total number of observations (N) is 200, indicating the sample size used in the analysis.

Table 1: Logistic Regression Results

Participation	Coeff	Odds ratio	SD	Z
Cons	-1.4852		1.5177	-0.98
Sex	0.6551	1.93	0.4600	1.42
Education	0.2595	1.30	0.0732	3.54***
Experience	0.0160	1.02	0.0285	0.56
Social status	1.0190	2.77	0.4291	2.37**
Family size	-0.0682	0.93	0.1254	-0.54
Cultivated area	-0.6129	0.54	0.1553	-3.95***
Livestock holding	1.2600	3.53	0.2791	4.51***
Oxen owned	0.4682	1.60	0.2250	2.08**
Soil fertility status	0.3677	1.44	0.4671	0.79
Market distance	-0.0352	0.97	0.0674	-0.52
Credit	-0.3173	0.73	0.5665	-0.56
Extension	0.0040	1.00	0.00167	0.24
Irrigation dist	-0.7471	0.47	0.1750	-4.27***
LR $chi^2(13)$ = 106.80		Pseudo R^2 = 0.3052		
Prob > chi^2 = 0.0000		Log likelihood = -85.223		
Numb ons=200				

The balancing test results presented in Table 2 assess the effectiveness of the propensity score matching method in achieving covariate balance between the treated and control groups. The table provides information on the mean values, percentage reduction in bias, t-test statistics, and corresponding p-values for each covariate before and after matching. For instance, consider the variable p-score, which represents the propensity scores. Before matching, the mean value for the treated group is 0.7287 and for the control group is 0.27124, resulting in a significant bias of 186.8%. After matching, the mean values become 0.49545 for the treated group and 0.488 for the control group, with a reduced bias of 2.9%. The t-test statistic for the unmatched group is 13.21 with a p-value of 0.000, indicating a significant difference between the treated and control groups. However, after matching, the t-test statistic decreases to 0.15 with a p-value of 0.882, suggesting that the difference is no longer statistically significant, indicating improved balance. Similarly, for the variable SEXH (Sex), before matching, the mean values for the treated and control groups are 0.77 and 0.63, respectively, resulting in a bias of 30.8%. After matching, the mean values become 0.69565 for the treated group and 0.6744 for the control group, with a reduced bias of 4.7%. The t-test statistic decreases from 2.17 to 0.22, and the corresponding p-value increases from 0.031 to 0.829 after matching, indicating improved balance. Overall, the results suggest that the propensity score matching method has been effective in reducing covariate imbalance between the treated and control groups for most of the variables, as evidenced by the reduction in bias and the non-significant differences observed after matching for many covariates.

Table 2: Balancing Test for Covariate

Variable	Sample	Mean Treated	Control	%bias	%reduct Bias	t-test t	p>t
_pscore	Unmatched	.7287	.27124	186.8		13.21	0.000
	Matched	.49545	.488	2.9	98.5	0.15	0.882
SEXH	Unmatched	.77	.63	30.8		2.17	0.031
	Matched	.69565	.6744	4.7	84.8	0.22	0.829
EDUCHH	Unmatched	5.62	3.91	56.8		4.02	0.000
	Matched	4.7391	4.898	-5.3	90.7	-0.24	0.814
EXPFARM	Unmatched	26.65	25.35	17.1		1.21	0.228
	Matched	26.304	24.72	20.8	-21.5	0.93	0.355
SSO	Unmatched	.73	.54	40.1		2.83	0.005
	Matched	.6521	.6097	9.0	77.6	0.42	0.677
HHSIZE	Unmatched	5.64	5.25	22.6		1.60	0.112
	Matched	5.3261	5.121	11.8	47.5	0.54	0.593
CULTSIZE	Unmatched	3.017	4.109	-76.0		-5.37	0.000
	Matched	3.588	3.545	3.0	96.1	0.15	0.881
LIVESTOC	Unmatched	1.854	1.328	60.7		4.29	0.000
	Matched	1.468	1.508	-4.7	92.3	-0.23	0.820
OXNUMB	Unmatched	1.56	1.28	32.5		2.30	0.023
	Matched	1.478	1.425	6.1	81.2	0.27	0.789
SOILFERT	Unmatched	.77	.74	6.9		0.49	0.624
	Matched	.7391	.7437	-1.1	84.7	-0.05	0.96
MARKTD	Unmatched	10.136	10.64	-16.1		-1.14	0.258
	Matched	10.141	10.27	-4.1	74.4	-0.20	0.841
CREDIT	Unmatched	.14	.18	-10.9		-0.77	0.443
	Matched	.152	.143	2.3	78.4	0.12	0.908
EXTCONTC	Unmatched	25.38	23.94	12.3		0.87	0.387
	Matched	24.13	24.45	-2.7	77.7	-0.13	0.898
IRRID	Unmatched	1.341	3.738	-21.9		-1.55	0.124
	Matched	1.859	1.914	-0.5	97.7	-0.18	0.858

4. CONCLUSIONS

The study focused on assessing the effects of small-scale irrigation on farm households' income generation and food security status in the central East Hararghe lowland areas of Oromia, Ethiopia. Several factors were identified as significant influencers of participation in irrigation farming. These included the education level of the household head, proximity to irrigation schemes, cultivated land area, livestock ownership, the number of oxen owned, and involvement in social organizations. These factors likely played crucial roles in shaping farmers' decisions to engage in irrigation activities, thereby impacting their income generation and food security outcomes. In conducting the propensity score matching, careful attention was paid to ensure that participant households were effectively matched with non-participant households based on a range of pre-participation characteristics. This rigorous approach helps to mitigate potential biases and ensures that any observed differences in outcomes between the two groups can be attributed to the treatment participation effect rather than confounding factors. Furthermore, by discarding households whose characteristics fell outside the common support region, the matching process focused on households that were truly comparable in terms of their propensity to participate in irrigation farming. This enhances the validity and reliability of the comparisons made between participant and non-participant households, providing valuable insights into the impact of small-scale irrigation on income generation and food security status in the central East Hararghe lowland areas of Oromia, Ethiopia. The rigorous matching process employed in this study ensured that the resulting matches met stringent criteria for quality and comparability. Various tests, including t-tests, reduction in standard bias, and chi-square tests, were conducted to validate the matching and ensure that participant and non-participant households were adequately balanced across key characteristics. Subsequent impact estimation revealed significant differences in farm income and food security status between households participating in small-scale irrigation and those that did not. These findings suggest that participation in irrigation activities had a tangible effect on household

livelihoods and food security, underscoring the importance of small-scale irrigation interventions in improving economic outcomes for rural communities in the central East Hararghe lowland areas of Oromia, Ethiopia. The findings of this study underscore the crucial role of participation in irrigation activities in enhancing farm household income and food security. By increasing agricultural productivity and reducing vulnerability to climate variability, irrigation can significantly improve the welfare of rural farm households. As such, it is imperative for government agencies, non-governmental organizations, and other stakeholders to continue supporting and investing in irrigation development programs. Encouraging and expanding efforts in irrigation not only benefits individual farmers but also contributes to the overall agricultural production and food security of the country. By bolstering rural livelihoods and strengthening resilience to environmental shocks, investments in irrigation hold the potential to uplift communities and drive sustainable economic development. Therefore, sustained commitment and collaboration across various sectors are essential to realizing the full potential of irrigation in improving the well-being of rural populations and advancing national food security objectives.

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